Use of a remotely steerable "robotic" catheter in a branched endovascular aortic graft

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We report the use of a remotely steerable catheter to treat kinked renal bridging stents 8 months after branched endovascular repair of a type III thoracoabdominal aortic aneurysm. Conventional techniques using single, coaxial, and manually steerable sheaths proved too unstable to provide the support required to pass a wire against resistance through the kinked stent. A remotely steerable "robotic" catheter provided sufficient precision and stability to cross the kink and reline it with an additional stent, restoring renal perfusion. This technology can help achieve precise and stable introducer sheath position. Further evaluation is necessary to understand the wider applications. (J Vasc Surg 2012;55:223-5.)

The visualization and control of wire and catheter manipulations in endovascular surgery are less intuitive and less predictable than the direct handling of surgical instruments in open surgery. Introducing more realistic three-dimensional imaging into the operative field may help clarify the anatomy for the endovascular operator,[1,2] but the inconsistency of manipulations remain a challenge. In particular, it can be difficult to get introducer sheaths (also known as guide catheters) to track around angulated native and graft anatomy. Even when the desired position is achieved, introducer sheath instability can occur when a distal wire or catheter meets resistance to its passage, and the force (action) used for advancement also creates a force (reaction) that displaces the sheath away from its initial position. A number of technical improvisations have been reported[3,4] to help overcome these problems in fenestrated aneurysm repairs.

In clinical practice, most sheaths are introduced over a wire and may incorporate a curve to facilitate orientation of the tip with the target vessel. An alternative approach is a steerable sheath, in which the shape can be varied during the procedure using integrated pull-wires. The control of the shape may be through a direct control (eg, twist-grip) on the sheath (in this article referred to as "manually steerable sheaths") or through a master-slave computer control system that allows remote control (referred to as "remotely steerable sheaths"). Manually steerable introducer sheaths are commercially available (eg, Agilis; St. Jude Medical Inc., St. Paul, Minn) and have proved useful, although they require additional hands to stabilize the sheath to maintain a given curvature and to resist reaction forces. Current commercially available remotely steerable catheters use a computer to translate the command inputs of the operator into movement of the sheath using servo-motors to adjust command pull-wires in the sheath. One feature of this system is that reaction forces at the distal end of the sheath are resisted by the tension in the pull-wires and servo-motors and will tend to return the sheath to its initial position. This creates an inherently more stable sheath than standard non-steerable or manually-steerable sheaths, although this adds complexity and cost to the procedure.

CASE REPORT

A 62-year-old man underwent total endovascular repair of a 9.9-cm Crawford type III thoracoabdominal aortic aneurysm, using a three-branched endovascular graft (Cook Medical, Brisbane, Australia) introduced through the right femoral artery. Bridging covered self-expanding stents were positioned via a left axillary arteriotomy into the left and right renal arteries (7-mm × 6-cm Fluency stent grafts; CR Bard Inc, Karlsruhe, Germany), and the superior mesenteric artery (9-mm × 6-cm Fluency stent graft; CR Bard Inc). All covered stents were reinforced with uncovered self-expanding stents (Zilver; Cook Medical, Bloomington, Ind). The procedure and recovery was uneventful, and the patient was discharged home on the third postoperative day.

A routine computed tomography surveillance scan at 4 months postoperation confirmed successful exclusion of the aneurysm sac and preservation of flow to all target vessels (Fig 1). No signs suggestive of branch kinking were seen.

Eight months postoperation, the patient was transferred as an emergency to our unit with anuria and hyperkalemia caused by bilateral renal branch occlusion. Attempts to negotiate the occlusions were unsuccessful despite prolonged efforts (over 3 hours) using 7F sheaths and a wide variety of catheters and wires. The next day, a further attempt through the left axillary artery using an 8.5F manually steerable catheter (Agilis; St Jude Medical Inc), itself stabilized inside a 12F sheath, allowed the sheath to be pushed inside the proximal end of the left renal side branch, which then allowed a wire to be pushed through the kink. A further self-expanding stent (7-mm × 4-cm Zilver; Cook Medical) opened the occlusion. This restored distal renal arterial flow, and renal

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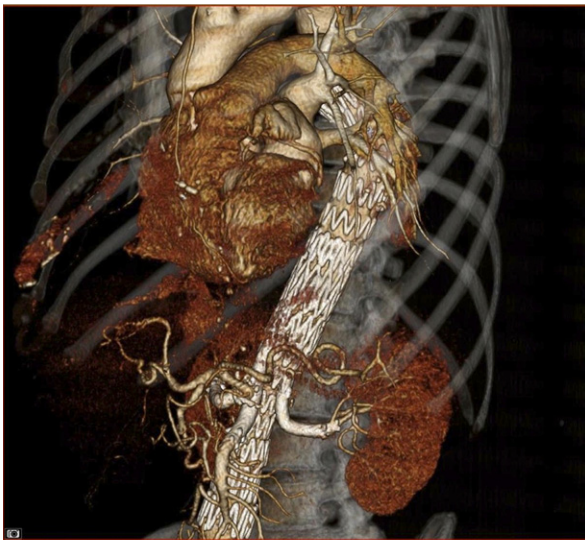

Fig 1. Four-month follow-up computed tomography showing exclusion of the aneurysm and preservation of blood flow to both kidneys and the superior mesenteric artery.

parenchyma was seen to enhance with contrast. Attempts to position the manually steerable sheath inside the right renal branch were thwarted by proximal aortic angulation above, preventing the single curved sheath reaching the side branch.

In view of the angiographic evidence suggesting that some functioning renal parenchyma on the left had been preserved, our nephrologists felt that all efforts should be made to restore flow to the right kidney, citing reports of delays in revascularization as long as 39 days still resulting in recovered renal function in native kidneys.[5]

The Artisan (Hansen Medical, Mountain View, Calif) remotely steerable catheter is in clinical use in our institution for cardiac electrophysiology ablation procedures and has two separate curves, which we anticipated would allow its positioning into the right renal branch. Furthermore, the 16-mm minimum diameter of curvature was expected to allow a 180 degree rotation within the 22-mm tapered graft diameter. Local institutional clinical governance approval and informed patient consent was sought and given to use this system. The contingency in the event of failure would be open iliorenal bypass.

Under general anesthesia, a coaxial Artisan steerable catheter was introduced through a 14F sheath in the right femoral artery and connected to the Sensei remote control manipulator ("robot"). Remote manipulation of the proximal and distal curves allowed rapid positioning of the sheath within the right renal branch. Resistance to the passage of a wire through the branch kink caused a reaction force on the sheath, although the sheath resisted this force without further control inputs, returning to its initial position (Fig 2; Movie 1, online only). A further self-expanding stent (7-mm × 4-cm Zilver; Cook Medical) opened the branch and restored distal perfusion and renal parenchymal enhancement (Fig 3; Movie 2, online only). The total iodinated contrast volume across the three attempts was approximately 30 mL.

The clinical outcome has been disappointing despite the technical success. After 2 months, the patient started passing urine, but 6 months later, although still passing moderate volumes of urine, he continues to require intermittent renal dialysis.

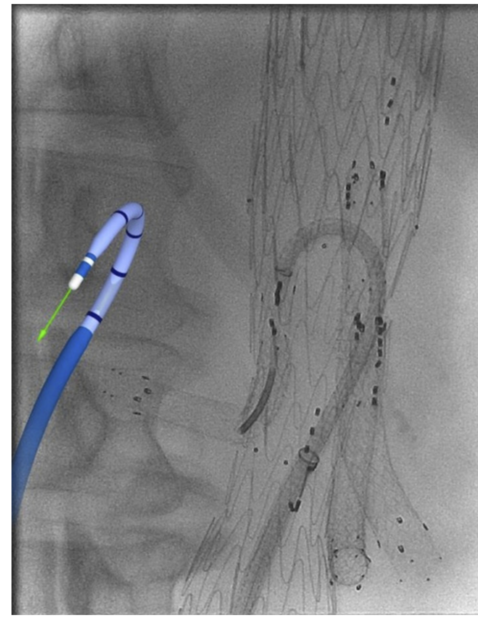

Fig 2. Tip of the Artisan catheter steered directly into the graft side branch (proximal end marked by *three dots*, distal by *two dots)*. This gave a stable position to abut the kink with a Cobra catheter and enabled a wire to be negotiated across against resistance, without losing sheath and catheter position. Dynamic images can be seen in Movie 1, online only.

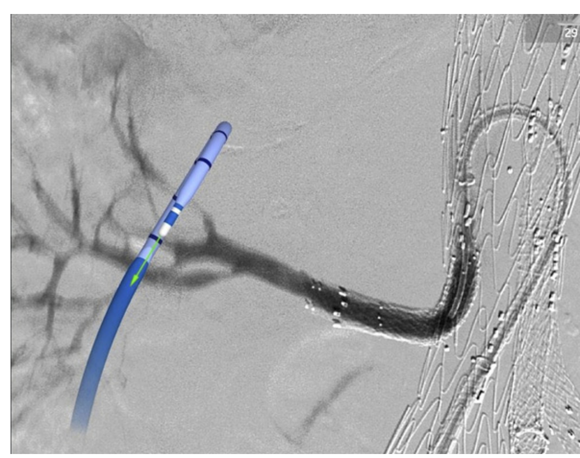

Fig 3. Digital subtraction angiogram after placement of a 7-mm × 4-cm self-expanding stent to correct the kink. Distal renal arterial flow and early renal parenchymal enhancement can be seen. Dynamic images can be seen in Movie 2, online only.

DISCUSSION

One possible strategy to overcome the challenges of achieving precise, stable sheath positioning in complex anatomy is the use of a steerable catheter. A remotely steerable catheter has been previously used for cannulating a limb of an aortic endovascular graft[6]; however, we believe our case is the first reported instance of using the technology to achieve success when other standard techniques have failed. In our case, the tight radius of curvature of the steerable catheter permitted a 180 degree turn within the narrow constraints the graft and precise positioning directly into the side branch. As had been experienced on the contralateral side, some force was required to pass a wire through the kink but, despite the tight distal curve on the catheter, we suspect the remotely steerable catheter maintained its shape due to the constant tension exerted by the servo-motors on the pull-wires. This provided both a stable platform for crossing the lesion as well as a stable curve through which the uncovered stent could be tracked.

It is arguable that no attempt to revascularize the renal arteries should have been undertaken, as this was always going to be a futile procedure, particularly as the occlusions must have taken place sometime before clinical presentation with hyperkalemia and even longer before revascularization could occur. However, our nephrological advice, further bolstered by the promising angiographic appearances after the first successful revascularization, was that efforts should be exhausted in the hope of avoiding long-term dialysis. Unfortunately, although some filtration function recovered – the patient started to and continues to pass urine – there was insufficient recovery to avoid dialysis. It is, of course, a matter of opinion whether another clinician in another center could have succeeded using standard techniques, not least because there are almost countless permutations of multiple sheaths, wire, and catheter combinations: each available in different models and lengths from different manufacturers and able to be introduced through a number of puncture sites, using various adjunctive techniques such as through-and-through wires and buddy wires. We tried all standard techniques (including manually steerable catheters) that we believed might succeed and here simply report that in this case, the remotely steerable provided a stable accurate configuration that allowed us to succeed where previous standard techniques have failed.

It seems likely that this technology will find further applications in clinical settings that might be facilitated by enhanced introducer sheath stability: some possible applications include the treatment of chronic total occlusions, placement of bridging stents in complex grafts, and carotid intervention. The advantages of the remotely steerable catheter technology will need to be balanced by the disadvantages in terms of added complexity, ergonomic impact, and capital and consumable costs. Combining steerable catheter technology with emerging technologies in three-dimensional visualization of anatomy and catheter localization may widen the scope of what is possible with endovascular intervention even further. Further clinical development and evaluation of these rapidly evolving technologies is essential.

CONCLUSION

Remotely steerable "robotic" catheters can help achieve precise and stable sheath position where conventional techniques have failed. This technology may prove useful in other clinical settings where sheath stability enhances the chances of procedural success.

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